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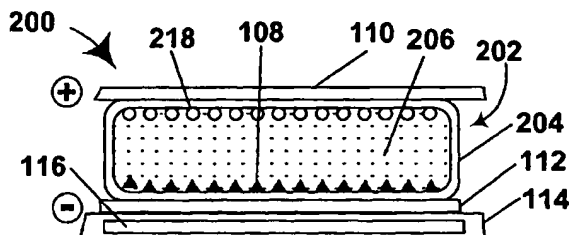
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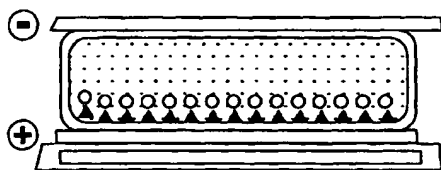
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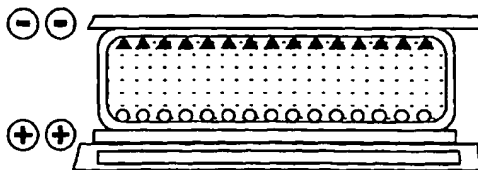
(54) Title: **ELECTROPHORETIC DISPLAYS CONTAINING MAGNETIC PARTICLES**



**A**



**B**



**C**

(57) Abstract: An electrophoretic medium (200) comprises a plurality of one or more types of particles suspended in a suspending fluid (206). The particles include at least one electrically charged, electrophoretically mobile particle (208) capable of translating through the suspending fluid (206) upon application of an electric field to the medium (200) and at least one magnetic particle (108). A magnet (116) is disposed adjacent the electrophoretic medium (200) to introduce a threshold resistance to magnetic particle movement.



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## **ELECTROPHORETIC DISPLAYS CONTAINING MAGNETIC PARTICLES**

This invention relates to electrophoretic displays containing magnetic (i.e., ferromagnetic or ferrimagnetic) particles, and to media for use in such displays.

5 More specifically, this invention relates to such displays and media in which the magnetic particles are used either to provide a threshold for switching of the optical states of the displays and media, or to allow the displays and media to exhibit more than two colors at any one pixel.

Electrophoretic displays have been the subject of intense research and

10 development for a number of years. Such displays can have attributes of good brightness and contrast, wide viewing angles, optical state bistability, and low power consumption when compared with liquid crystal displays. (The terms "bistable" and "bistability" are used herein in their conventional meaning in the art to refer to displays comprising display elements having first and second display states differing in at least

15 one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element.) Nevertheless, problems with the long-term

20 image quality of these displays have prevented their widespread usage. For example, particles that make up electrophoretic displays tend to settle, resulting in inadequate service-life for these displays.

Numerous patents and applications assigned to or in the names of the Massachusetts Institute of Technology and E Ink Corporation have recently been

25 published describing encapsulated electrophoretic media. Such encapsulated media comprise numerous small capsules, each of which itself comprises an internal phase containing electrophoretically mobile particles suspended in a liquid suspension medium, and a capsule wall surrounding the internal phase. Typically, the capsules are

themselves held within a polymeric binder to form a coherent layer positioned between two electrodes. Encapsulated media of this type are described, for example, in U.S. Patents Nos. 5,930,026; 5,961,804; 6,017,584; 6,067,185; 6,118,426; 6,120,588; 6,120,839; 6,124,851; 6,130,773; 6,130,774; 6,172,798; 6,177,921; 6,232,950; 5 6,241,921; 6,249,271; 6,252,564; 6,262,706; 6,262,833; 6,300,932; 6,312,304; 6,312,971; 6,323,989; 6,327,072; 6,376,828; and 6,377,387; U.S. Patent Application Publication Nos. 2001-0045934; 2002-0018042; 2002-0019081; and 2002-0021270; and International Applications Publication Nos. WO 97/04398; WO 98/03896; WO 98/19208; WO 98/41898; WO 98/41899; WO 99/10767; WO 99/10768; WO 99/10769; 10 WO 99/47970; WO 99/53371; WO 99/53373; WO 99/56171; WO 99/59101; WO 99/67678; WO 00/03349; WO 00/03291; WO 00/05704; WO 00/20921; WO 00/20922; WO 00/20923; WO 00/26761; WO 00/36465; WO 00/36560; WO 00/36666; WO 00/38000; WO 00/38001; WO 00/59625; WO 00/60410; WO 00/67110; WO 00/67327 WO 01/02899; WO 01/07691; WO 01/08241; WO 01/08242; WO 01/17029; WO 15 01/17040; WO 01/17041; WO 01/80287 and WO 02/07216. The entire disclosures of all these patents and published applications are herein incorporated by reference.

Known electrophoretic media, both encapsulated and unencapsulated, can be divided into two main types, referred to hereinafter for convenience as "single particle" and "dual particle" respectively. A single particle medium has only a single 20 type of electrophoretic particle suspended in a colored medium, at least one optical characteristic of which differs from that of the particles. (In referring to a single type of particle, we do not imply that all particles of the type are absolutely identical. For example, provided that all particles of the type possess substantially the same optical characteristic and a charge of the same polarity, considerable variation in parameters 25 such as particle size and electrophoretic mobility can be tolerated without affecting the utility of the medium.) The optical characteristic is typically color visible to the human eye, but may, alternatively or in addition, be any one or more of reflectivity, retroreflectivity, luminescence, fluorescence, phosphorescence, or color in the broader sense of meaning a difference in absorption or reflectance at non-visible wavelengths.

When such a medium is placed between a pair of electrodes, at least one of which is transparent, depending upon the relative potentials of the two electrodes, the medium can display the optical characteristic of the particles (when the particles are adjacent the electrode closer to the observer, hereinafter called the "front" electrode) or the optical  
5 characteristic of the suspending medium (when the particles are adjacent the electrode remote from the observer, hereinafter called the "rear" electrode, so that the particles are hidden by the colored suspending medium).

A dual particle medium has two different types of particles differing in at least one optical characteristic and a suspending fluid which may be uncolored or  
10 colored, but which is typically uncolored. The two types of particles differ in electrophoretic mobility; this difference in mobility may be in polarity (this type may hereinafter be referred to as an "opposite charge dual particle" medium) and/or magnitude. When such a dual particle medium is placed between the aforementioned pair of electrodes, depending upon the relative potentials of the two electrodes, the  
15 medium can display the optical characteristic of either set of particles, although the exact manner in which this is achieved differs depending upon whether the difference in mobility is in polarity or only in magnitude. For ease of illustration, consider an electrophoretic medium in which one type of particles are black and the other type white. If the two types of particles differ in polarity (if, for example, the black particles  
20 are positively charged and the white particles negatively charged), the particles will be attracted to the two different electrodes, so that if, for example, the front electrode is negative relative to the rear electrode, the black particles will be attracted to the front electrode and the white particles to the rear electrode, so that the medium will appear black to the observer. Conversely, if the front electrode is positive relative to the rear  
25 electrode, the white particles will be attracted to the front electrode and the black particles to the rear electrode, so that the medium will appear white to the observer.

If the two types of particles have charges of the same polarity, but differ in electrophoretic mobility (this type of medium may hereinafter to referred to as a "same polarity dual particle" medium), both types of particles will be attracted to the

same electrode, but one type will reach the electrode before the other, so that the type facing the observer differs depending upon the electrode to which the particles are attracted. For example suppose the previous illustration is modified so that both the black and white particles are positively charged, but the black particles have the higher electrophoretic mobility. If now the front electrode is negative relative to the rear electrode, both the black and white particles will be attracted to the front electrode, but the black particles, because of their higher mobility, will reach it first, so that a layer of black particles will coat the front electrode and the medium will appear black to the observer. Conversely, if the front electrode is positive relative to the rear electrode, both the black and white particles will be attracted to the rear electrode, but the black particles, because of their higher mobility will reach it first, so that a layer of black particles will coat the rear electrode, leaving a layer of white particles remote from the rear electrode and facing the observer, so that the medium will appear white to the observer: note that this type of dual particle medium requires that the suspending fluid to sufficiently transparent to allow the layer of white particles remote from the rear electrode to be readily visible to the observer. Typically, the suspending fluid in such a display is not colored at all, but some color may be incorporated for the purpose of correcting any undesirable tint in the white particles seen therethrough.

Both single and dual particle electrophoretic displays may be capable of intermediate gray states having optical characteristics intermediate the two extreme optical states already described.

Many of the aforementioned patents and applications recognize that the walls surrounding the discrete microcapsules in an encapsulated electrophoretic medium could be replaced by a continuous phase, thus producing a so-called "polymer-dispersed electrophoretic display" in which the electrophoretic medium comprises a plurality of discrete droplets of an electrophoretic fluid and a continuous phase of a polymeric material, and that the discrete droplets of electrophoretic fluid within such a polymer-dispersed electrophoretic display may be regarded as capsules or microcapsules even though no discrete capsule membrane is associated with each

individual droplet; see for example, WO 01/02899, at page 10, lines 6-19 and United States Application Serial No. 09/683,903 filed February 28, 2002, the entire disclosure of which is herein incorporated by reference. Accordingly, for purposes of the present application, such polymer-dispersed electrophoretic media are regarded as sub-species of encapsulated electrophoretic media.

An encapsulated electrophoretic display typically does not suffer from the clustering and settling failure mode of traditional electrophoretic devices and provides further advantages, such as the ability to print or coat the display on a wide variety of flexible and rigid substrates. (Use of the word "printing" is intended to include all forms of printing and coating, including, but without limitation: pre-metered coatings such as patch die coating, slot or extrusion coating, slide or cascade coating, curtain coating; roll coating such as knife over roll coating, forward and reverse roll coating; gravure coating; dip coating; spray coating; meniscus coating; spin coating; brush coating; air knife coating; silk screen printing processes; electrostatic printing processes; thermal printing processes; ink jet printing processes; and other similar techniques.) Thus, the resulting display can be flexible. Further, because the display medium can be printed (using a variety of methods), the display itself can be made inexpensively.

One problem with existing electrophoretic displays, whether encapsulated or unencapsulated, is that they have essentially no threshold for switching, i.e., that even a small electric field applied for a long period will cause the display to switch between its optical states. This lack of a threshold has hitherto prevented electrophoretic displays from being addressed by passive matrix techniques, and has necessitated the use of active matrix techniques. Active matrix addressing schemes, such as the use of thin film transistor (TFT) arrays having at least one transistor for each pixel of the display, are substantially more expensive than passive matrix addressing schemes, and hence the cost of electrophoretic displays could be reduced if an electrophoretic medium could be provided which had a switching threshold.

Another problem in most electrophoretic displays is that any individual pixel can only display two colors (the colors of the dye and the single particle in a single particle display, or the colors of the two different types of particles in a dual particle display) together with intermediate gray states between these two colors, and this inability to display more than two colors leads to difficulties in providing full color displays. If, for example, one wishes to provide an electrophoretic display which imitates a book having black text on white paper, with occasional use of spot color for illustrations, it is highly desirable that each pixel of such a display be capable of showing pure black and pure white in order that the display can produce sharp, highly legible text, since the human eye is much more sensitive to loss of resolution in text than in colored graphic images. However, if each pixel is to display both pure black and pure white, color images can only be produced if each pixel is also capable of displaying a third color.

Alternatively, if the electrophoretic display is to be used to provide a full color RGB or CMY display (for example, as a substitute for a color liquid crystal display), the reflective nature of an electrophoretic display leads to problems in obtaining satisfactory color saturation. For example, if one provides a display which can produce color images on a white background by using three types of dual particle capsules having respectively white/red, white/green and white/blue states, when a red color is desired at most only one-third of the area of the display can be switched to red, and the resultant color will not appear highly saturated. If each capsule could display three colors, one could use capsules having white/red/green, white/green/blue and white/blue/red states, so that when a red color is desired about two-thirds of the area of the display could be switched to red, resulting in a substantially more saturated red.

The aforementioned U.S. Patent No. 6,017,584 and published International Application WO 99/10768 describe and claim an encapsulated electrophoretic display in which each capsule contains three different types of particles, each having a different color, the three types of particles having substantially non-overlapping electrophoretic mobilities. By applying to such a capsule a sequence of

electrical pulses controlled in both time and amplitude, the capsule can display the color of any selected one of the three types of particles. While this type of display can give good results, in some cases it may be difficult to ensure that the three types of particles can retain substantially non-overlapping electrophoretic mobilities over a range of operating conditions, so that some "muddying" of the colors may result. Also, since at least three separate pulses are required to display one of the three colors, the switching of such a display will be slower than that of a dual particle display.

It has now been realized that the aforementioned problems with electrophoretic displays can be reduced or eliminated by including in the display at least one type of particle which is magnetic, and the present invention relates to electrophoretic media and displays including magnetic particles.

Accordingly, this invention provides an electrophoretic medium comprising a plurality of one or more types of particles suspended in a suspending fluid, said particles including at least one electrically charged, electrophoretically mobile particle, and at least one magnetic particle. The present medium may comprise a type of particle which is both magnetic and electrophoretically mobile, or it may include a first type of particle which is magnetic but not electrophoretically mobile, and a second type of particle which is non-magnetic but is electrophoretically mobile; in either case, the medium may comprise an additional type of particle which is non-magnetic but is electrophoretically mobile. This invention also extends to an electrophoretic display comprising an electrophoretic medium of the present invention and at least one electrode disposed adjacent to this medium.

The media and displays provided by the present invention may be of any of the types (namely single particle, opposite charge dual particle, and same polarity dual particle) previously described. One embodiment of the invention, illustrated below in Figure 1, is a single particle medium in which the particles are both magnetic and electrophoretically mobile and suspended in a colored suspending fluid; this embodiment provides a single particle two color medium with a switching threshold. A second embodiment of the invention, illustrated in Figure 2, is a dual particle medium in

which one type of particle is magnetic and electrophoretically mobile, bearing a charge of one polarity, and the second type of particle is non-magnetic but is electrophoretically mobile, bearing a charge of opposite polarity to the first type of particle. There are two variants of this second embodiment. In the first variant, the  
5 suspending fluid is uncolored; this provides a dual particle two color medium with a switching threshold. In the second variant, the suspending fluid is colored; this provides a three color medium. A third embodiment of the invention, illustrated in Figure 3, comprises a three particle medium having first and second types of particles which are non-magnetic but electrophoretically mobile, these two types of particles  
10 having charges of opposite polarity, and a third type of particle which is magnetic. Again, there are two variants of this embodiment, depending upon whether the third type of particle is or is not electrophoretically mobile. Normally, the third type of particle will be electrophoretically mobile and will bear a charge of the same polarity as one of the first and second types of particles. However, it is possible to have the third  
15 type of particle not be electrophoretically mobile, and to write on such a display using a magnetic writing head. (Obviously, even if a magnetic particle is electrophoretically mobile, it can still be addressed by a magnetic writing head when it is not subject to an electric field.) Finally, a fourth embodiment of the invention, illustrated in Figure 4, comprises a three particle medium having first and second types of particles which are  
20 non-magnetic but electrophoretically mobile, these two types of particles having charges of the same polarity, and a third type of particle which is magnetic and electrophoretically mobile, bearing a charge of opposite polarity to the first and second types of particles.

This invention also provides a first method of addressing an  
25 electrophoretic medium, the method comprising:

(a) providing an electrophoretic medium having opposed first and second surfaces, the medium comprising a suspending fluid having a first optical characteristic, and a plurality of electrically charged magnetic particles suspended in the suspending fluid, the particles having a second optical characteristic different from the

first optical characteristic, the medium having a magnet disposed adjacent its first surface;

5 (b) allowing the particles to remain adjacent the first surface of the display under the magnetic forces applied to the particles by the magnet, thereby causing the first optical characteristic of the fluid to be visible at the second surface of the medium; and

(c) applying to the medium an electric field having a polarity and magnitude sufficient to cause the particles to move through the suspending fluid against the magnetic forces applied to the particles by the magnet, thereby causing the particles  
10 to move adjacent the second surface of the medium and the second optical characteristic of the particles to be visible at the second surface.

This invention also provides a second method of addressing an electrophoretic medium, the method comprising:

(a) providing an electrophoretic medium having opposed first and second  
15 surfaces, the medium comprising a suspending fluid, a plurality of a first type of electrically charged magnetic particles having a first optical characteristic suspended in the suspending fluid, and a plurality of a second type of electrically charged non-magnetic particles having a second optical characteristic different from the first optical characteristic, the second type of particles bearing charges of opposite polarity to the  
20 charges on the first type of particles, the medium having a magnet disposed adjacent its first surface;

(b) applying to the medium an electric field having a polarity which causes the second type of particles to move adjacent the second surface of the medium, while causing the first type of particles to remain adjacent the first surface of the  
25 medium, thereby causing the second optical characteristic to be visible at the second surface; and

(c) applying to the medium an electric field having a polarity and magnitude sufficient to cause the first particles to move through the suspending fluid against the magnetic forces applied to the first particles by the magnet, thereby causing

the first particles to move adjacent the second surface of the medium and the first optical characteristic to be visible at the second surface, while the second particles move adjacent the first surface of the medium.

5 This invention also provides a third method of addressing an electrophoretic medium, the method comprising:

(a) providing an electrophoretic medium having opposed first and second surfaces, the medium comprising a suspending fluid, a plurality of a first type of electrically charged magnetic particles having a first optical characteristic suspended in the suspending fluid, a plurality of a second type of electrically charged non-magnetic particles having a second optical characteristic different from the first optical characteristic, the first and second types of particles bearing charges of the same polarity, and a third type of electrically charged non-magnetic particles having a third optical characteristic different from the first and second optical characteristics, the third type of particles bearing charges of opposite polarity to those on the first and second types of particles, the medium having a magnet disposed adjacent its first surface;

10

15

(b) applying to the medium an electric field having a polarity which causes the third type of particles to move adjacent the second surface of the medium, while causing the first and second types of particles to remain adjacent the first surface of the medium, thereby causing the third optical characteristic to be visible at the second surface;

20

(c) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second type of particles to move adjacent the second surface of the medium and the third type of particles to move adjacent the first surface of the medium, but insufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces acting on the first type of particles, thereby causing the second optical characteristic to be visible at the second surface; and

25

(d) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second type of particles to move adjacent the second

surface of the medium and the third type of particles to move adjacent the first surface of the medium, the magnitude of the electric field being sufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces acting on the first type of particles and lie adjacent the second surface of the medium, thereby causing the first and second optical characteristics to be visible at the second surface.

This invention also provides a fourth method of addressing an electrophoretic medium, the method comprising:

(a) providing an electrophoretic medium having opposed first and second surfaces, the medium comprising a suspending fluid, a plurality of a first type of electrically charged magnetic particle having a first optical characteristic suspended in the suspending fluid, a plurality of a second type of electrically charged non-magnetic particle having a second optical characteristic different from the first optical characteristic, the first and second types of particles bearing charges of opposite polarity, and a plurality of a third type of electrically charged non-magnetic particle having a third optical characteristic different from the first and second optical characteristics, the second and third types of particles bearing charges of the same polarity, but the second type of particle having higher electrophoretic mobility than the third type of particle, the medium having a magnet disposed adjacent its first surface;

(b) applying to the medium an electric field having a polarity which causes the second and third types of particles to move adjacent the second surface of the medium with the second type of particles lying closer to the second surface, so that the second optical characteristic is visible at the second surface, the first type of particles lying adjacent the first surface of the medium;

(c) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second and third types of particles to move adjacent the first surface of the display, with the third type of particles lying closer to the second surface, the magnitude of the electric field being insufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces

acting on the first type of particles, thereby causing the third optical characteristic to be visible at the second surface; and

5 (d) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second and third types of particles to move adjacent the first surface of the medium, the magnitude of the electric field being sufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces acting on the first type of particles and lie adjacent the second surface of the medium, thereby causing the first optical characteristic to be visible at the second surface.

10 Finally, this invention also provides a fifth method of addressing an electrophoretic medium, to provide a threshold and/or to increase the number of optical states which can be displayed by the medium, the method comprising:

15 providing an electrophoretic medium having opposed first and second surfaces, the medium comprising a suspending fluid having a first optical characteristic, and a plurality of electrically charged magnetic particles suspended in the suspending fluid, the medium having a magnet disposed adjacent its first surface;

20 applying to the medium an electric field having a polarity and magnitude which tends to cause the particles to move towards the second surface of the medium but which is insufficient to overcome the magnetic forces applied to the particles by the magnet, thereby the particles to remain adjacent the first surface of the medium; and

applying to the medium an electric field having a polarity and magnitude sufficient to cause the particles to move through the suspending fluid against the magnetic forces applied to the particles by the magnet, thereby causing the particles to move adjacent the second surface of the medium,

25 the optical state of the medium varying depending upon whether the particles are adjacent the first or second surface of the medium.

Although other magnetic particles may be employed, the preferred magnetic material for use in the media and displays of the present invention is iron tetroxide ( $\text{Fe}_3\text{O}_4$ ), usually known as "magnetite" or "lodestone", the most common

mineral forms of this material. This material is inexpensive and can readily be reduced to the particle size range (about 0.25 to 5  $\mu\text{m}$ ) required for use in electrophoretic displays. In all the embodiments of the present invention, it is preferred that at least the magnetic particles bear a polymer coating, this polymer coating preferably being  
5 formed by one of the processes described in copending Application Serial No. 60/291,061 filed May 15, 2001. It has been found difficult to produce, in the hydrocarbon-based suspending fluids typically used in electrophoretic media, a dispersion of magnetite particles which is stable for a sufficiently long period to be commercially useful unless the magnetite is polymer coated. Indeed, it is preferred that  
10 all the particles in the present media bear polymer coatings produced as described in this copending application, since such coatings are useful in increasing the stability of electrophoretic media containing particles bearing charges of opposite polarity.

Magnetite itself is of course black in color. In many embodiments of the invention, the magnetite may be used in this black form. However, in other cases,  
15 magnetic particles of other colors may be desired, and in such cases the magnetic particles may comprise magnetite coated with another pigment. For example, if white magnetic particles are desired, magnetite could be coated with titania by conventional processes such as those used commercially to coat titania on to mica. More generally, the magnetic particles used in the present invention may comprise a core of magnetic  
20 material and a shell of non-magnetic material substantially completely surrounding the core; the shell may itself bear a polymer coating or other surface treatment.

Preferred embodiments of the present invention will now be described, though by way of illustration only, with reference to the accompanying drawings, in which:

25 Figures 1A-1C are schematic side elevations showing various states of a first electrophoretic display of the present invention, in which the electrophoretic medium comprises a single type of particle, which is both magnetic and electrophoretically mobile, in a colored suspending liquid;

Figures 2A-2C are schematic side elevations showing various states of a second electrophoretic display of the present invention, in which the electrophoretic medium comprises one type of particle which is magnetic and electrophoretically mobile, bearing a charge of one polarity, and a second type of particle which is non-magnetic but is electrophoretically mobile, bearing a charge of opposite polarity to the first type of particle;

Figures 3A-3C are schematic side elevations showing various states of a third electrophoretic display of the present invention, in which the electrophoretic medium comprises one type of particle which is magnetic and electrophoretically mobile, bearing a charge of one polarity, a second type of particle which is non-magnetic but is electrophoretically mobile, bearing a charge of opposite polarity to the first type of particle, and a third type of particle which is non-magnetic but is electrophoretically mobile, bearing a charge of the same polarity as the first type of particle; and

Figures 4A-4C are schematic side elevations showing various states of a fourth electrophoretic display of the present invention, in which the electrophoretic medium comprises one type of particle which is magnetic and electrophoretically mobile, bearing a charge of one polarity, and second and third types of particle which are non-magnetic but are electrophoretically mobile, both the second and third types of particles bearing a charge of opposite polarity to the first type of particle, the second and third types of particles differing from each other in electrophoretic mobility.

The first electrophoretic display (generally designated 100) of the invention shown in Figures 1A-1C comprises an encapsulated electrophoretic medium (generally designated 102) comprising a plurality of capsules 104 (only one of which is shown in Figures 1A-1C), each of which contains a suspending liquid 106 and dispersed therein a plurality of a single type of particle 108, which for purposes of illustration will be assumed to be black. The particles 108 are both magnetic and electrophoretically mobile and are preferably formed of magnetite. In the following description, it will be assumed that the particles 108 are positively charged, although of course negatively

charged particles could also be used if desired. (The triangular shape of the particles 108, and the square and circular shapes of other particles discussed below, are used purely by way of illustration to enable the various types of particles to be distinguished easily in the accompanying drawings, and in no way correspond to the physical forms of the actual particles, which are typically substantially spherical. It should be stressed that, unlike some prior art magnetophoretic displays, in which particles are moved magnetically but not electrostatically, the present displays normally do not rely upon the contrast between face-on and edge-on views of flat, flake-like magnetic particles, and will operate satisfactorily with substantially spherical particles. However, we do not exclude the use of non-spherical particles in the present displays.)

The display 100 further comprises a common, transparent front electrode 110, which forms a viewing surface through which an observer views the display 100, and a plurality of discrete rear electrodes 112, each of which defines one pixel of the display 100 (only one rear electrode 112 is shown in Figures 1A-1C). For ease of illustration and comprehension, Figures 1A-1C show only a single microcapsule forming the pixel defined by rear electrode 112, although in practice a large number (20 or more) microcapsules are normally used for each pixel. The rear electrodes 112 are mounted upon a substrate 114, which contains a magnetic sheet 116, which may be formed from any convenient magnetic material, for example bonded ferrite, ceramic hard ferrite, aluminum-nickel-cobalt alloys (Alnico), or a rare earth magnetic material, such as samarium cobalt or neodymium iron boron. The magnetic material should have north and south poles alternating transversely across the width of the magnetic sheet 116, with poling widths less than about 500  $\mu\text{m}$ . Preferably the poling widths should be half the width of the capsules in the electrophoretic medium. Such magnets may be purchased from Group Arnold (300 N. West St., Marengo, IL, 60152 - Group Arnold is a Registered Trademark). For reasons explained below, the magnetic sheet 116 should lie adjacent the rear electrodes 112 but does not need to be incorporated into the substrate 114; for example, the magnetic sheet 116 could lie between the rear electrodes

112 and the substrate 114, or on the opposed side of the substrate 114 from the rear electrodes 112.

5 The suspending liquid 106 is colored such that the particles 108 lying in the positions shown in Figure 1A adjacent the rear electrodes 112 are not visible to an observer viewing the display 100 via the front electrode 110. Since the colored suspending liquid 106 and the particles 108 render the electrophoretic medium 102 opaque, the rear electrodes 112 and the substrate 114 can be transparent or opaque since they are not visible through the opaque electrophoretic medium 102.

10 The capsules 104 and the particles 108 can be made in a wide range of sizes. However, in general it is preferred that the thickness of the capsules, measured perpendicular to the electrodes, be in the range of about 15 to 500  $\mu\text{m}$ , while the particles 108 will typically have diameters in the range of about 0.25 to about 2  $\mu\text{m}$ .

Figure 1A shows the display 100 with no charges on the electrodes 110 and 112. Under this condition, the magnetic particles 108 are attracted to the magnetic sheet 116 and thus lie adjacent the rear electrode 112, where they are hidden from an observer viewing the display 100 through the front electrode 110 by the colored liquid 106. Accordingly, the pixel shown in Figure 1A displays to the observer the color of the liquid 106, which for purposes of illustration will be assumed to be white. Obviously, since the particles 108 are assumed to be positively charged, this white state of the pixel will not change if the rear electrode 112 is negatively charged relative to the front electrode 110, since under such conditions the particles 108 will be held against the rear electrode 112 by both magnetic and electrostatic forces. (Although the display 100 is illustrated in Figures 1A-1C with the rear electrodes 112 at the bottom, in practice both the front and rear electrodes are typically disposed vertically for maximum visibility of the display 100. None of the preferred displays described herein rely in any way upon gravity to control the movement of the particles; such movement under gravity is in practice far too slow to be useful for controlling particle movement.)

25 Figure 1B shows the display 100 with the front electrode 110 made slightly negative relative to the rear electrode 112, as indicated by the single negative

sign adjacent the front electrode 110. Since the particles 108 are positively charged, they will be weakly attracted to the slightly negatively charged front electrode 110, but in the situation shown in Figure 1B, this weak electrostatic attraction is insufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 remain adjacent the rear electrode 112 and the pixel continues to display the white color of the liquid 106.

Figure 1C shows the display 100 with the front electrode 110 made highly negative relative to the rear electrode 112, as indicated by the double negative sign adjacent the front electrode 110. The positively charged particles 108 are now strongly electrostatically attracted to the highly negative front electrode 110, and this strong electrostatic attraction is sufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 move adjacent the front electrode 110, and the pixel displays the black color of the particles 108.

Thus, the provision of the magnetic particles 108 and the magnetic sheet in the display 100 provides a switching threshold for the display; the illustrated pixel of the display does not switch when the front electrode 110 is made slightly negative relative to the rear electrode 112, but does switch when the front electrode 110 is made highly negative relative to the rear electrode 112. Thus, the display 100 could be addressed by passive matrix techniques.

In Figures 1A-1C, the capsules 104 are illustrated as being of substantially prismatic form, having a width (parallel to the planes of the electrodes) significantly greater than their height (perpendicular to these planes). This prismatic shape of the capsules 104 is deliberate. If the capsules 104 were essentially spherical, in the black state shown in Figure 1C, the particles 108 would tend to gather in the highest part of the capsule, in a limited area centered directly above the center of the capsule. The color seen by the observer would then be essentially the average of this central black area and a white annulus surrounding this central area, where the white liquid 106 would be visible. Thus, even in this supposedly black state, the observer would see a grayish color rather than a pure black, and the contrast between the two

extreme optical states of the pixel would be correspondingly limited. In contrast, with the prismatic form of microcapsule shown in Figure 1C, the particles 108 cover essentially the entire cross-section of the capsule so that no, or at least very little white liquid is visible, and the contrast between the extreme optical states of the capsule is enhanced. For further discussion on this point, and on the desirability of achieving close-packing of the capsules within the electrophoretic layer, the reader is referred to the aforementioned U.S. Patent No. 6,067,185, and the corresponding published International Application WO 99/10767.

The second electrophoretic display (generally designed 200) of the invention shown in Figures 2A-2C comprises an encapsulated electrophoretic medium (generally designated 202) comprising a plurality of capsules 204, each of which contains a suspending liquid 206 and dispersed therein a plurality of magnetic, positively charged black particles 108 identical discussed to those in the first display 100 discussed above. The display 200 further comprises a front electrode 110, rear electrodes 112, a substrate 114 and a magnetic sheet 116, all of which are identical to the corresponding integers in the first display 100. However, in addition to the black particles 108, there are suspended in the liquid 206 a plurality of negatively charged, non-magnetic particles 218.

There are two variants of the display 200 depending upon whether the liquid 206 is uncolored or colored. First, assume that the liquid 206 is uncolored (i.e., essentially transparent although as mentioned earlier, some coloration of the liquid 206 may be used to adjust the colors displayed) and the particles 218 are white. Figure 2A shows the display 200 with the front electrode 110 positively charged relative to the rear electrode 112 of the illustrated pixel; in this polarity, the size of the potential difference between the electrodes is essentially irrelevant. The positively charged particles 108 are held adjacent the rear electrode 112 by both magnetic and electrostatic forces, while the negatively charged particles 218 are held electrostatically against the front electrode 110. Accordingly, an observer viewing the display 200 through the front electrode 110

sees a white pixel, since the white particles 218 are visible and hide the black particles 108.

Figure 2B shows the display 200 with the front electrode 110 slightly negatively charged relative to the rear electrode 112 of the illustrated pixel. As in the corresponding situation shown in Figure 1B, the positive charged particles 108 will be weakly attracted to the negatively charged front electrode 110, but this weak electrostatic attraction is insufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 remain adjacent the rear electrode 112. The particles 218, which are subject to electrostatic but not magnetic forces, move towards the rear electrode 112 and (provided a sufficient number of particles 218 are present, which is easy to arrange in practice) these white particles 218 form a continuous white layer overlying and hiding the layer of black particles 108. Accordingly, an observer viewing the display 200 through the front electrode 110 still sees a white pixel, since the white particles 218 are visible through the uncolored liquid 206 and hide the black particles 108.

Finally, Figure 2C shows the display 200 with the front electrode 110 highly negatively charged relative to the rear electrode 112 of the illustrated pixel. As in the corresponding optical state shown in Figure 1C, the positively charged particles 108 are now strongly electrostatically attracted to the highly negative front electrode 110, and this strong electrostatic attraction is sufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 move adjacent the front electrode 110, and the pixel displays the black color of the particles 108, which hide the white particles 218.

Thus, as with the first display of the invention, in the second display 200, the provision of the magnetic particles 108 and the magnetic sheet 216 provides a switching threshold for the display; the illustrated pixel of the display does not switch when the front electrode 110 is made slightly negative relative to the rear electrode 112, but does switch when the front electrode 110 is made highly negative relative to the rear electrode 112. Thus, the display 200 could be addressed by passive matrix techniques.

As already mentioned, there is a second variant of the display 200 shown in Figures 2A-2C which uses a colored suspending liquid 206; as previously described, coloration of the liquid 206 may be achieved by dissolving a dye in the liquid or by providing a nanoparticle pigment suspension in the liquid. For purposes of illustration, suppose that in the second variant, the particles 108 are again black, the particles 218 are again white, but that the suspending liquid 206 is colored; this color will be assumed to be red for purposes of illustration. Obviously, in this second variant the movement of the particles are exactly the same as in the first variant, so that the situation shown in Figure 2A displays a white pixel and the optical state shown in Figure 2C displays a black pixel. However, with the red liquid 206, in the optical state shown in Figure 2B, the observer sees the red color of the liquid 206, but not the white color of the particles 218 nor the black color of the particles 108, since both sets of particles are hidden by the red liquid 206. Accordingly, in Figure 2B, the observer sees a red pixel, so that this variant provides a three-color pixel.

The third electrophoretic display (generally designated 300) of the invention shown in Figures 3A-3C comprises an encapsulated electrophoretic medium (generally designated 302) comprising a plurality of capsules 304, each of which contains an uncolored suspending liquid 306 and dispersed therein a plurality of magnetic, positively charged black particles 108 and a plurality of non-magnetic, negatively charged white particles 218, both sets of particles being identical to those in the second display 200 discussed above. The display 300 further comprises a front electrode 110, rear electrodes 112, a substrate 114 and a magnetic sheet 116, all of which are identical to the corresponding integers in the first and second displays 100 and 200 respectively. However, in addition to the particles 108 and 218, there are suspended in the liquid 306 a plurality of positively charged, non-magnetic particles 320, which differ in color from both sets of particles 108 and 218, and which for purposes of illustration will be assumed to be red.

Figure 3A shows the display 300 with the front electrode 110 positively charged relative to the rear electrode 112 of the illustrated pixel; in this polarity, the size

of the potential difference between the electrodes is essentially irrelevant. As in the corresponding optical state shown in Figure 2A, the positively charged particles 108 are held adjacent the rear electrode 112 by both magnetic and electrostatic forces, while the negatively charged particles 218 are held electrostatically against the front electrode 110. The non-magnetic positively charged particles 320 are held against the rear electrode 112 by electrostatic forces only. Accordingly, an observer viewing the display 300 through the front electrode 110 sees a white pixel, since the white particles 218 are visible and hide both the black particles 108 and the red particles 320. (Note that in this display state, it does not matter whether the black particles 108 and the red particles 320 form two separate layers, as illustrated in Figure 3A, or the reverse situation with the red particles 320 closer to the rear electrode 112, or the two types of particles are intermingled in a single layer, since in all cases both the black particles 108 and the red particles 320 are hidden by the white particles 108.

Figure 3B shows the display 300 with the front electrode 110 slightly negatively charged relative to the rear electrode 112 of the illustrated pixel. As in the corresponding optical state shown in Figure 2B, the positive charged particles 108 will be weakly attracted to the negatively charged front electrode 110, but this weak electrostatic attraction is insufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 remain adjacent the rear electrode 112. The negatively charged particles 218 move adjacent the rear electrode 112, while the red positively charged particles 320 move adjacent the front electrode 110. Accordingly, an observer viewing the display 300 through the front electrode 110 sees a red pixel, since the red particles 320 adjacent the front electrode 110 are visible and hide the black particles 108 and the white particles 218. (As in the optical state shown in Figure 3A, in the optical state shown in Figure 3B, it makes no visible difference whether the black particles 108 and the white particles 218 form two separate layers or are intermingled in a single layer.)

Finally, Figure 3C shows the display 300 with the front electrode 110 highly negatively charged relative to the rear electrode 112 of the illustrated pixel. As

in the corresponding optical state shown in Figure 2C, the positively charged particles 108 are now strongly electrostatically attracted to the highly negative front electrode 110, and this strong electrostatic attraction is sufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108  
5 move adjacent the front electrode 110. The positively charged particles 320 will also move adjacent the front electrode 110, while the negatively charged particles 218 will move adjacent the rear electrode 112.

The exact appearance of the pixel in Figure 3C depends upon the population of black particles 108 and red particles 320 immediately adjacent the front  
10 electrode 110, since these are the only particles visible to an observer viewing the display through this electrode. In practice, despite the way in which Figures 3A-3C are drawn for purposes of illustration, it is not advisable to generate the optical state shown in Figure 3C from that shown in Figure 3B, since in this case the red particles already present adjacent the front electrode 110 will tend to block access of the black particles  
15 and the pixel shown in Figure 3 will appear essentially red. Instead, the display state shown in Figure 3C should be generated by abruptly reversing polarity on the electrodes in the state shown in Figure 3A, so that the black particles 108 and red particles 320 move together from adjacent the rear electrode 112 to adjacent the front electrode and form a mixed layer of black and red particles, as illustrated in Figure 3C. The resultant  
20 mixture of black and red particles immediately adjacent the front electrode 110 will present a dark, essentially black appearance to the observer. In a preferred form of this third embodiment, the black particles 108 have a substantially higher electrophoretic mobility than the red particles 320 so that when the polarity of the electrodes in the optical state shown in Figure 3A is abruptly reversed, the black particles 108 move  
25 more swiftly than the red particles 320 towards the front electrode 110, so that the final layer of particles immediately adjacent this electrode is predominantly if not exclusively comprised of black particles, and thus the pixel displays a true black color to the observer. The black particles 108 and the red particles 320 of course hide the white particles 218 from the observer.

The fourth electrophoretic display (generally designed 400) of the invention shown in Figures 4A-4C comprises an encapsulated electrophoretic medium (generally designated 402) comprising a plurality of capsules 404. The display 400 further comprises a front electrode 110, rear electrodes 112, a substrate 114 and a magnetic sheet 116, all of which are identical to the corresponding integers in the three displays 100, 200 and 300 previously described. The display 400 closely resembles the display 300 described above in that the liquid 406 is uncolored and in that black positively charged magnetic particles 108 and white negatively charged non-magnetic particles 218 are suspended therein. However the display 400 differs from the display 300 in that the red positively charged non-magnetic particles 320 are replaced by red *negatively* charged non-magnetic particles 420, which have a substantially lower electrophoretic mobility than the white particles 218.

Figure 4A shows the display 400 with the front electrode 110 positively charged relative to the rear electrode 112 of the illustrated pixel; in this polarity, the size of the potential difference between the electrodes is essentially irrelevant. As in the corresponding optical states shown in Figures 2A and 3A, the positively charged particles 108 are held adjacent the rear electrode 112 by both magnetic and electrostatic forces. Both the negatively charged white particles 218 and the negatively charged red particles 420 are attracted to the front electrode 110, but since the white particles 218 have substantially higher electrophoretic mobility, they reach the front electrode 110 first (note that the optical state shown in Figure 4A is normally generated by abruptly reversing the polarity of the electrodes in either of the optical states shown in Figures 4B and 4C, thus forcing both the white particles 218 and the red particles 420 to traverse the thickness of the capsule 404, and thus allowing the greater mobility of the white particles 218 to cause them to reach their positions adjacent the front electrode 110 before the red particles 420). Thus, the white particles 218 form a continuous layer immediately adjacent the front electrode 110, thereby hiding both the red particles 420 and the black particles 108. Accordingly, an observer viewing the display 400 through

the front electrode 110 sees a white pixel, since the white particles 218 are visible and hide both the black particles 108 and the red particles 420.

Figure 4B shows the display 400 with the front electrode 110 slightly negatively charged relative to the rear electrode 112 of the illustrated pixel. As in the corresponding optical states shown in Figures 2B and 3B, the positively charged particles 108 will be weakly attracted to the negatively charged front electrode 110, but this weak electrostatic attraction is insufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 remain adjacent the rear electrode 112. Both the negatively charged white particles 218 and the negatively charged red particles 420 are attracted to the rear electrode 112, but since the white particles have higher electrophoretic mobility, when the optical state shown in Figure 4B is produced by reversing the polarity on the electrodes in the optical state shown in Figure 4A, the white particles 218 reach the rear electrode 112 more quickly than do the red particles 420, so that the white particles 218 form a continuous layer of particles overlying the black particles 108, and leaving a continuous layer of the red particles 420 facing the front electrode 110. Accordingly, an observer viewing the display 400 through the front electrode 110 sees a red pixel, since the red particles 420 are visible and hide the black particles 108 and the white particles 218.

Finally, Figure 4C shows the display 400 with the front electrode 110 highly negatively charged relative to the rear electrode 112 of the illustrated pixel. As in the corresponding optical states shown in Figures 2C and 3C, the positively charged particles 108 are now strongly electrostatically attracted to the highly negative front electrode 110, and this strong electrostatic attraction is sufficient to overcome the magnetic attraction of the particles 108 to the magnetic sheet 116. Accordingly, the particles 108 move adjacent the front electrode 110. The negatively charged red particles 420 and the negatively charged white particles 218 remain adjacent the rear electrode 112 (it makes no visible difference whether the red particles 420 and the white particles 218 form two separate layers or intermingle in a single layer). Accordingly, an observer viewing the display 400 through the front electrode 110 sees a black pixel,

since the black particles 108 are visible and hide the red particles 420 and the white particles 218.

5 Apart from the provision of the magnetic particles, the electrophoretic media and displays of the present invention may employ the same components and manufacturing techniques as in the aforementioned Massachusetts Institute of Technology and E Ink Corporation patents and applications, to which the reader is referred for further information.

10 The following Examples are now given, though by way of illustration only, to show details of particularly preferred reagents, conditions and techniques used in the electrophoretic media and displays of the present invention. All centrifuging mentioned was carried out on a Beckman GS-6 or Allegra 6 centrifuge (available from Beckman Coulter, Inc., Fullerton, CA 92834).

#### Example 1

15 This Example illustrates the provision of a silica coating on a magnetic particle which may be used in the present media and displays. The procedure used is adapted from U.S. Patent No. 3,639,133.

20 Magnetite ( $\text{Fe}_3\text{O}_4$ , 50g, ground to an average particle size of about 0.1 to 0.6  $\mu\text{m}$ ; the material used was Bayferrox 303T, available from Bayer AG, Leverkusen, Germany – “BAYFERROX” is a Registered Trade Mark) was placed in a sodium silicate solution (415 ml of a 0.073M solution with 1.9% sodium hydroxide), and the resultant mixture was rapidly stirred in air and then sonicated at 30-35°C. The suspension was then heated to 90-95°C over a period of 1 hour and sulfuric acid (150 ml of a 0.22 M solution) and additional sodium silicate (75 ml of a 0.83 M solution with 0.2% sodium hydroxide) were added simultaneously over a period of 2.5 to 3 hours, 25 with stirring. After these additions had been completed, the reaction mixture was stirred for an additional 15 minutes, then cooled slowly to room temperature, added to plastic bottles and centrifuged at 3500 rpm for 15 minutes. The supernatant liquor was decanted, and the silica-coated pigment re-dispersed in deionized water and centrifuged

at 3500 rpm for 15 minutes. The washing was repeated twice more, and the pigment finally dried in air for 24 hours, and then in an oven at 85°C for 2 hours.

### **Example 2**

5 This Example illustrates reaction of the silica-coated pigment prepared in Example 1 with a bifunctional reagent in the first stage of a process to provide a polymer-coated magnetite useful in the electrophoretic media and displays of the present invention.

To a mixture of ethanol (1000 ml) and water (100 mL), concentrated ammonium hydroxide was added until the pH reached 9.0-9.5, N-[3-(trimethoxysilyl)-propyl]-N'-(4-vinylbenzyl)ethylene diamine hydrochloride (40 g of a 40 weight per cent solution in methanol) was added, and the resultant solution was stirred rapidly for 4 minutes. The silica-coated magnetite (50 g) prepared in Example 1 was then added, and the mixture stirred rapidly for 7 minutes. The resultant suspension was poured into plastic bottles and centrifuged at 3500 rpm for 30 minutes. The supernatant liquor was decanted, and the silanized pigment re-dispersed in ethanol and centrifuged at 3500 rpm on the same centrifuge for 30 minutes, and the liquid decanted. The washing was repeated, and the pigment finally dried in air for 18 hours, then under vacuum at 70°C for 2 hours.

### **Example 3**

20 This Example illustrates conversion of the silanized pigment produced in Example 2 to the corresponding polymer-coated magnetite.

The silanized pigment produced in Example 2 (50 g) was placed in a round-bottomed flask with toluene (50 g) and lauryl methacrylate (50 g). The resultant mixture was stirred rapidly under a nitrogen atmosphere (argon may alternatively be used) for 20 minutes, then slowly heated to 50°C and AIBN (0.5 g in 10 ml of toluene) added quickly. The suspension was then heated to 65°C and stirred at this temperature under nitrogen for a further 18 hours. The resultant viscous suspension was poured into plastic bottles, the flask being washed out with ethyl acetate to remove residual product and the ethyl acetate solution added to the bottles. The bottles were centrifuged at 3500

rpm for 30 minutes. The supernatant liquor was decanted, and the polymer-coated pigment re-dispersed in ethyl acetate and centrifuged at 3500 rpm for 30 minutes, and the liquid decanted. The washing was repeated, and the pigment dried in air until a workable powder was obtained, and then under vacuum at 65°C for 6 to 18 hours.

5

#### Example 4

This Example illustrates the preparation of a polymer-coated titania useful in the electrophoretic media and displays of the present invention.

##### Part A : Preparation of silanized titania

To a 4 L glass reactor equipped with a stirrer and a pH meter were added  
10 ethanol (930.7 g) and deionized water (69.3 g), and the resultant solution was stirred at 150 rpm. The probe of the pH meter was inserted into the reactor and the pH of the mixture was lowered to 4.5 by adding glacial acetic acid from a pipette. The pH probe was then removed, 3-(trimethoxysilyl)propyl methacrylate (160.0 g) was added to the reactor, and the reaction mixture was stirred for a further 5 minutes. The mixing speed  
15 was then increased to 250 rpm, titania (1000 g of du Pont R960) was added to the reactor, and the reaction mixture was stirred for a further 10 minutes. The mixing speed was then decreased to 200 rpm, ethanol (1826.6 g) was added to the reactor, and stirring was continued for 1 minute. The reaction mixture was then drained into six 750 ml centrifuge bottles and centrifuged at 3000 rpm for 20 minutes. The supernatant liquor  
20 was discarded and the solids dried in air overnight and then under vacuum for 4 hours at 65°C.

##### Part B : Preparation of polymer-coated pigment

To a 4 L glass reactor equipped with a water bath, a nitrogen source, a condenser, a stirrer and a septum were added lauryl methacrylate (960 g) and toluene  
25 (1386 g). The mixture was stirred at 200 rpm and the water bath was set to 50°C to preheat the reactor. The silanized titania (750 g, prepared in Part A above) was weighed out and any large chunks crushed manually. The mixer speed was then increased to 300 rpm and the silanized titania was added to the reactor, which was then purged with nitrogen. Separately AIBN (5.64 g) was dissolved in toluene (150 g) and the resultant

solution loaded into a syringe pump, the output needle of which was pushed through the septum into the reactor. Once the reactor temperature had stabilized at 50°C, the AIBN solution was pumped into the reaction mixture at a uniform rate over a period of 1 hour. The reaction mixture was then held at 50°C with stirring overnight, then drained into six  
5 750 ml centrifuge bottles, which were filled with toluene and shaken until a substantially uniform dispersion was obtained. The bottles were then centrifuged at 3000 rpm for 30 minutes, the supernatant liquor was discarded, and the toluene dispersion, centrifugation and decantation steps repeated. Finally, the bottles were allowed to dry in air overnight, and then in vacuum at 65°C for 4 hours.

10

#### **Example 5**

This Example illustrates the construction of an encapsulated dual particle display using the polymer-coated pigments prepared in Examples 3 and 4.

15

The suspending fluid used is a mixture of a 1:1 w/w mixture of a hydrocarbon (Isopar-G, available commercially from Exxon Corporation, Houston, Texas; "Isopar" is a Registered Trade Mark) and a halogenated hydrocarbon oil (Halogenated hydrocarbon oil 1.8, available commercially from Halogenated Hydrocarbon Products Corporation, River Edge, New Jersey – referred to hereinafter for simplicity as "Halocarbon"); this mixture is hereinafter referred to as "1:1 Isopar/Halocarbon mixture". The suspending fluid contains Solsperse 17000 (available  
20 commercially from Avecia Ltd., Blackley, Manchester, United Kingdom; "Solsperse" is a Registered Trade Mark) as a charge control agent, and Span 85 (sold by ICI Americas, Inc., Wilmington, Delaware; "Span" is a Registered Trade Mark) as a dispersant.

20

#### **Part A : Preparation of internal phase**

25

To make approximately 100 ml of internal phase ready for encapsulation, there were used 3.219 g of polymer-coated magnetite prepared in Example 3 above and 4.438 g of polymer-coated titania prepared in Example 4 above. These pigments were mixed with Solsperse 17000 dispersant (0.444 g. added in the form of a 10 w/w % solution in Isopar G), Span 85 dispersant (0.444 g) and the 1:1 w/w Isopar/Halocarbon

mixture (99.112 g). The resultant solution was well shaken and stored on a roll mill for at least 24 hours before being used in the encapsulation process.

Part B : Encapsulation

5 The internal phase thus prepared was then encapsulated using a reactor equipped with a water jacket, an overhead stirrer, a dropping funnel and a pH meter. Gelatin (4.5 g) was dissolved in deionized water (262.2 g) at 40°C with stirring, care being taken to ensure that no foam was produced on the surface of the solution. Separately, acacia (3.33 g) was dissolved in deionized water (65.56 g) and the resultant solution heated to 40°C. Also separately, the internal phase described above was heated  
10 to 40°C and then added to the gelatin solution; the gelatin solution was stirred during the addition, which was conducted by introducing the internal phase through the dropping funnel, the outlet of which was placed below the surface of the gelatin solution. After the addition of the internal phase was complete, the rate of stirring was increased and the stirring continued for 30 minutes at 40°C in order to emulsify the  
15 internal phase into droplets having an average diameter of about 200 µm.

The acacia solution was then added over a period of about 1 minute, care being taken to avoid foaming. The pH of the mixture was lowered to 4.82 using 10 per cent aqueous acetic acid, and the vigorous stirring was continued to a further 40 minutes at the same temperature. The temperature of the mixture was lowered to 10°C over a  
20 period of two hours, with continued vigorous stirring, and glutaraldehyde (1.7 g) was added. After this addition, the mixture was gradually warmed to 25°C and stirred vigorously overnight. Finally, stirring was discontinued, and the mixture was allowed to settle for 10-15 minutes, during which time a foamy mixture separated on top of the liquid.

25 The liquid phase was then removed, leaving the foamy mixture in the reactor, and the capsules in this liquid phase washed three times by sedimentation and redispersion in deionized water. The capsules were separated by size to yield a distribution between 100 and 300 µm diameter, with a mean diameter of about 200 µm;

such a distribution can be effected by hand sieving the capsules to produce the final capsule slurry.

Part C : Production of electrophoretic display

5 The resulting capsule slurry was centrifuged and then mixed with an aqueous urethane binder (NeoRez R-9320) at a ratio of 1 part by weight binder to 9 parts by weight of capsules, and 0.3 weight per cent of hydroxypropylmethylcellulose was added as a slot-coating additive. The resultant mixture was slot coated on to a 125  $\mu\text{m}$  thick indium-tin oxide coated polyester film moving at 1 m/sec relative to the slot coating head. The coated film was allowed to air dry for 10 minutes, then oven dried at 10 50°C for 15 minutes to produce an electrophoretic medium approximately 50  $\mu\text{m}$  thick containing essentially a single layer of capsules (see the aforementioned published International Patent Application WO 00/20922).

To provide an experimental electrophoretic display, comprising only a single pixel, which could be used to investigate the properties of the electrophoretic medium thus prepared, the capsule-coated surface of the coated film was then 15 overcoated with the aforementioned NeoRez R-9320 binder using a doctor blade with a 13 mil (330  $\mu\text{m}$ ) gap setting (this binder serves both to planarize the capsule-coated surface and as a lamination adhesive) and the overcoated film dried at 50°C for 20 minutes. The dried film was then hot laminated to a second polyester film coated, on 20 the side facing the electrophoretic medium, with indium tin oxide to produce the final electrophoretic display.

The resulting dual particle display could be switched between its black and white states in not more than 500 msec by applying a voltage of 42 V across the indium tin oxide electrode, or more slowly by applying only 10 V across the electrodes. 25 However, when a bonded ferrite magnetic sheet, of the type used in so-called "refrigerator magnets", was placed in contact with one of the polyester sheets, the display could not be switched at 10 V, thus showing that the magnetite particles were being retained adjacent the electrode closer to the magnet, despite the electric field produced by the applied voltage. However, even with the magnet present, the display

switched at 42 V. Thus, the inclusion of the magnetic particles provided a threshold for switching of this display.

#### Example 6

5 This Example illustrates the construction of an encapsulated display generally similar to that constructed in Example 5 above, but also containing chromium oxide particles

Chromium oxide ( $\text{Cr}_2\text{O}_3$ , 50g, ground to an average particle size of about 0.1 to 0.6  $\mu\text{m}$ ; the material used was Bayer Green GX, available from Bayer AG, Leverkusen, Germany) was silica coated and then polymer-coated in the same manner  
10 as described in Examples 1 to 3 above. Thermogravimetric analysis of the polymer-coated product showed a weight loss of about 3.55 per cent.

An encapsulated three particle display was then constructed using this polymer-coated chromium-oxide and the polymer-coated pigments prepared in Examples 3 and 4.

15 To make approximately 100 ml of internal phase ready for encapsulation, there were used 4.154 g of polymer-coated magnetite prepared in Example 3 above, 5.548 g of polymer-coated titania prepared in Example 4 above and 4.147 g of the polymer-coated chromium oxide. These pigments were mixed with Solsperse 17000 dispersant (0.555 g. added in the form of a 10 w/w % solution in Isopar G), Span 85  
20 dispersant (0.555 g) and the 1:1 w/w Isopar/Halocarbon mixture (98.89 g). The resultant solution was well shaken and stored on a roll mill for at least 24 hours before being used in the encapsulation process.

Encapsulation and production of the electrophoretic display were conducted in the same manner as in Example 5 above.

25 One polyester sheet of the resulting three-particle display was placed in contact with a bonded ferrite magnetic sheet, of the type used in so-called "refrigerator magnets", and viewed through the other polyester sheet. Upon application of 10 V pulses across the electrodes, the display switched between white and green colored states in not more than 500 msec, thus showing that the magnetite particles were being

retained adjacent the electrode closer to the magnet, despite the electric field produced by the applied voltage. When the drive voltage was increased to 42 V, the display switched between white and black states in not more than 500 msec, even with the magnet present, the black state being the result of both black and green particles being present adjacent the sheet through which the display was viewed. Thus, the inclusion of the magnetic particles enabled three optical states to be produced in the single pixel of this display.

#### Example 7

This Example illustrates the construction of an encapsulated display generally similar to that constructed in Example 6 above but containing iron oxide particles in place of the chromium oxide particles.

Iron oxide ( $\text{Fe}_2\text{O}_3$ , 50g, ground to an average particle size of about 0.1 to 1.2  $\mu\text{m}$ ; the material used was APC 944 Synthetic Red Iron Oxide, available from Alabama Pigments Company, Greenpond, Alabama 35074, United States of America) was silica coated and then polymer coated in the same manner as described in Examples 1 to 3 above. Thermogravimetric analysis of the polymer-coated product showed a weight loss of about 8.30 per cent.

An encapsulated three-particle display was then constructed using this polymer-coated iron oxide and the polymer-coated pigments prepared in Examples 3 and 4 above.

To make approximately 100 ml of internal phase ready for encapsulation, there were used 4.154 g of polymer-coated magnetite prepared in Example 3 above, 5.548 g of polymer-coated titania prepared in Example 4 above and 4.362 g of the polymer-coated red iron oxide. These pigments were mixed with Solsperse 17000 dispersant (0.555 g. added in the form of a 10 w/w % solution in Isopar G), Span 85 dispersant (0.555 g) and the 1:1 w/w Isopar/Halocarbon mixture (98.89 g). The resultant solution was well shaken and stored on a roll mill for at least 24 hours before being used in the encapsulation process.

Encapsulation and production of the electrophoretic display were conducted in the same manner as in Example 5 above.

5 The optical performance of the resultant display were tested in the same way as in Example 6 above, with similar results. At 10 V, the display switched between white and red colored states, but at 42 V, the display switched between white and black colored states. Thus, the inclusion of the magnetic particles enabled three optical states to be produced in the single pixel of the display.

#### Example 8

10 This Example illustrates the construction of an encapsulated display generally similar to that constructed in Example 6 above but using blue cobalt aluminate particles in place of the chromium oxide.

Cobalt aluminate ( $\text{CoAl}_2\text{O}_4$ , 50g, ground to an average particle size of about 0.1  $\mu\text{m}$ ; the material used was Bayer Light Blue 2R, available from Bayer AG, Leverkusen, Germany) was silica coated and then polymer coated in the same manner as described in Examples 1 to 3 above. Thermogravimetric analysis of the polymer-  
15 cated product showed a weight loss of about 7.95 per cent.

An encapsulated three-particle display was then constructed in the same manner as in Example 6 above but using the blue cobalt aluminate particles in place of the chromium oxide.

20 To make approximately 100 ml of internal phase ready for encapsulation, there were used 3.219 g of polymer-coated magnetite prepared in Example 3 above, 5.365 g of polymer-coated titania prepared in Example 4 above and 5.432 g of the polymer-coated blue cobalt aluminate. These pigments were mixed with Solsperse 17000 dispersant (0.537 g. added in the form of a 10 w/w % solution in Isopar G), Span  
25 85 dispersant (0.537 g) and the 1:1 w/w Isopar/Halocarbon mixture (98.93 g). The resultant solution was well shaken and stored on a roll mill for at least 24 hours before being used in the encapsulation process.

Encapsulation and production of the electrophoretic display were conducted in the same manner as in Example 5 above.

The optical performance of the resultant display were tested in the same way as in Example 6 above, with similar results. At 10 V, the display switched between white and blue colored states, but at 42 V, the display switched between white and black colored states. Thus, the inclusion of the magnetic particles enabled three optical states to be produced in the single pixel of the display.

#### Example 9

An encapsulated three-particle display was then constructed in the same manner as in Example 6 above but using yellow lead chromate particles in place of the chromium oxide.

Lead chromate ( $\text{PbCrO}_4$ , 50g, ground to an average particle size of about 0.1  $\mu\text{m}$  to 1.0  $\mu\text{m}$ ; the material used was Royal Yellow 6000, available from First Color Co., Ltd., Shihung City, Kyounggi-do, Korea) was silica coated and then polymer coated in the same manner as described in Examples 1 to 3 above. Thermogravimetric analysis of the polymer-coated product showed a weight loss of about 9.50 per cent.

An encapsulated three-particle display was then constructed using this polymer-coated lead chromate and the pigments prepared in Examples 3 and 4 above.

To make approximately 100 ml of internal phase ready for encapsulation, there were used 4.159 g of polymer-coated magnetite prepared in Example 3 above, 5.548 g of polymer-coated titania prepared in Example 4 above and 4.424 g of the polymer-coated yellow lead chromate. These pigments were mixed with Solsperse 17000 dispersant (0.555 g. added in the form of a 10 w/w % solution in Isopar G), Span 85 dispersant (0.555 g) and the 1:1 w/w Isopar/Halocarbon mixture (98.89 g). The resultant solution was well shaken and stored on a roll mill for at least 24 hours before being used in the encapsulation process.

Encapsulation and production of the electrophoretic display were conducted in the same manner as in Example 5 above.

The optical performance of the resultant display was tested in the same way as in Example 6 above, with similar results. At 10 V, the display switched between white and yellow colored states, but at 42 V, the display switched between white and

black colored states. Thus, the inclusion of the magnetic particles enabled three optical states to be produced in the single pixel of the display.

5 Numerous changes and modifications can be made in the preferred embodiments of the present invention already described without departing from the spirit and skill of the invention. For example, although the embodiments of the invention illustrated in the accompanying drawings all use permanent magnets, the present invention could make use of electromagnets; using electromagnets allows for switching the magnetic field off and on as required, and also varying the strength of the magnetic field to alter the operating conditions of the display. Similarly, although the  
10 embodiments of the invention illustrated in the accompanying drawings all use magnetic particles which are also electrostatically charged and hence electrophoretically mobile, the displays of the present invention may use magnetic particles which are not electrophoretically mobile. Displays using such magnetic but non-electrophoretically mobile particles could be addressed using a combined electrostatic and magnetic  
15 writing head.

## CLAIMS

- 1                   1.     An electrophoretic medium comprising a plurality of one or more  
2     types of particles suspended in a suspending fluid, the particles including at least one  
3     electrically charged, electrophoretically mobile particle capable of translating through  
4     the suspending fluid upon application of an electric field to the medium, the medium  
5     being characterized in that the particles comprise at least one magnetic particle.
- 1                   2.     An electrophoretic medium according to claim 1 characterized by  
2     at least one particle which is both magnetic and electrophoretically mobile.
- 1                   3.     An electrophoretic medium according to claim 2 characterized by  
2     a single type of magnetic, electrophoretically mobile particle in a colored suspending  
3     fluid.
- 1                   4.     An electrophoretic medium according to claim 2 characterized in  
2     that the magnetic, electrophoretically mobile particle has a first charge polarity and a  
3     first optical characteristic, and the medium further comprises a second type of particle  
4     which is non-magnetic, has a charge polarity opposite of the first charge polarity and  
5     has a second optical characteristic different from the first optical characteristic.
- 1                   5.     An electrophoretic medium according to claim 4 characterized in  
2     that the magnetic, electrophoretically mobile particle and the second type of particle,  
3     bear charge of opposite polarity.
- 1                   6.     An electrophoretic medium according to any one of claims 2 to 5  
2     characterized by a third type of particle which is non-magnetic, has a third  
3     electrophoretic mobility different from the first and second electrophoretic mobilities  
4     and a third optical characteristic different from the first and second optical  
5     characteristics.
- 1                   7.     An electrophoretic medium according to claim 6 characterized in  
2     that the second and third types of particles bear charges of opposite polarity.
- 1                   8.     An electrophoretic medium according to claim 6 characterized in  
2     that the second and third types of particles bear charges of the same polarity but differ in

3 electrophoretic mobility, and the magnetic particles bear charges of opposite polarity to  
4 those on the second and third types of particles.

1 9. An electrophoretic medium according to any one of the preceding  
2 claims characterized in that the magnetic particle comprises one or more of iron  
3 tetroxide ( $\text{Fe}_3\text{O}_4$ ), iron tetroxide/polymer composites, rare earth magnets and Alnico  
4 alloys.

1 10. An electrophoretic medium according to claim 9 characterized in  
2 that the magnetic particle(s) are in the size range of 0.25  $\mu\text{m}$  to 5  $\mu\text{m}$ .

1 11. An electrophoretic medium according to any one of the preceding  
2 claims characterized in that the magnetic particle(s) have a polymer coating.

1 12. An electrophoretic medium according to any one of the preceding  
2 claims characterized in that the magnetic particle(s) comprise a core of magnetic  
3 material and a shell of non-magnetic material substantially completely surrounding the  
4 core.

1 13. An electrophoretic medium according to any one of the preceding  
2 claims characterized by a plurality of capsules each having a capsule wall, the particles  
3 and the suspending fluid being contained within the capsules.

1 14. An electrophoretic medium according to claim 13 characterized  
2 in that the capsules are non-spherical.

1 15. An electrophoretic display comprising an electrophoretic medium  
2 and at least one electrode disposed adjacent the electrophoretic medium, the display  
3 being characterized in that the medium is a medium according to any one of the  
4 preceding claims.

1 16. An electrophoretic display according to claim 15 characterized by  
2 at least one magnet disposed adjacent the electrophoretic medium.

1 17. An electrophoretic display according to claim 16 characterized by  
2 a second electrode disposed adjacent the electrophoretic medium and opposite the first  
3 electrode, at least one of the electrodes being substantially transparent.

1                   18.    A method of addressing an electrophoretic medium, the method  
2    comprising:

3                   (a)    providing an electrophoretic medium having opposed first and  
4    second surfaces, the medium comprising a suspending fluid having a first optical  
5    characteristic, and a plurality of electrically charged particles suspended in the  
6    suspending fluid, the particles having a second optical characteristic different from the  
7    first optical characteristic, the method being characterized in that the particles are  
8    magnetic and the medium has a magnet disposed adjacent its first surface, the method  
9    also being characterized by:

10                  (b)    allowing the particles to remain adjacent the first surface of the  
11    display under the magnetic forces applied to the particles by the magnet, thereby  
12    causing the first optical characteristic of the fluid to be visible at the second surface of  
13    the medium; and

14                  (c)    applying to the medium an electric field having a polarity and  
15    magnitude sufficient to cause the particles to move through the suspending fluid against  
16    the magnetic forces applied to the particles by the magnet, thereby causing the particles  
17    to move adjacent the second surface of the medium and the second optical characteristic  
18    of the particles to be visible at the second surface.

1                   19.    A method of addressing an electrophoretic medium, the method  
2    comprising:

3                   (a)    providing an electrophoretic medium having opposed first and second  
4    surfaces, the medium comprising a suspending fluid, a plurality of a first type of  
5    electrically charged particles having a first optical characteristic suspended in the  
6    suspending fluid, and a plurality of a second type of electrically charged non-magnetic  
7    particle having a second optical characteristic different from the first optical  
8    characteristic, the second type of particles bearing charges of opposite polarity to the  
9    charges on the first type of particles, the medium having a magnet disposed adjacent its  
10   first surface, the method being characterized in that the first type of particles are

11 magnetic and the medium has a magnet disposed adjacent its first surface, the method  
12 also being characterized by:

13 (b) applying to the medium an electric field having a polarity which  
14 causes the second type of particles to move adjacent the second surface of the medium,  
15 while causing the first type of particles to remain adjacent the first surface of the  
16 medium, thereby causing the second optical characteristic to be visible at the second  
17 surface; and

18 (c) applying to the medium an electric field having a polarity and  
19 magnitude sufficient to cause the first particles to move through the suspending fluid  
20 against the magnetic forces applied to the first particles by the magnet, thereby causing  
21 the first particles to move adjacent the second surface of the medium and the first  
22 optical characteristic to be visible at the second surface, while the second particles move  
23 adjacent the first surface of the medium.

1 20. A method of addressing an electrophoretic medium, the method  
2 comprising:

3 (a) providing an electrophoretic medium having opposed first and  
4 second surfaces, the medium comprising a suspending fluid, a plurality of a first type of  
5 electrically charged particles having a first optical characteristic suspended in the  
6 suspending fluid, a plurality of a second type of electrically charged particles having a  
7 second optical characteristic different from the first optical characteristic, the first and  
8 second types of particles bearing charges of the same polarity,

9 the medium being characterized in that the first type of particles are  
10 magnetic and the second type of particles are non-magnetic, the medium further being  
11 characterized by a third type of electrically charged non-magnetic particles having a  
12 third optical characteristic different from the first and second optical characteristics, the  
13 third type of particles bearing charges of opposite polarity to those on the first and  
14 second types of particles;

15 the medium having a magnet disposed adjacent its first surface;

16                   (b)     applying to the medium an electric field having a polarity which  
17 causes the third type of particles to move adjacent the second surface of the medium,  
18 while causing the first and second types of particles to remain adjacent the first surface  
19 of the medium, thereby causing the third optical characteristic to be visible at the  
20 second surface;

21                   (c)     applying to the medium an electric field having a polarity and  
22 magnitude sufficient to cause the second type of particles to move adjacent the second  
23 surface of the medium and the third type of particles to move adjacent the first surface  
24 of the medium, but insufficient to cause the first type of particles to move away from  
25 the first surface of the medium against the magnetic forces acting on the first type of  
26 particles, thereby causing the second optical characteristic to be visible at the second  
27 surface; and

28                   (d)     applying to the medium an electric field having a polarity and  
29 magnitude sufficient to cause the second type of particles to move adjacent the second  
30 surface of the medium and the third type of particles to move adjacent the first surface  
31 of the medium, the magnitude of the electric field being sufficient to cause the first type  
32 of particles to move away from the first surface of the medium against the magnetic  
33 forces acting on the first type of particles and lie adjacent the second surface of the  
34 medium, thereby causing the first and second optical characteristics to be visible at the  
35 second surface

1                   21.     A method of addressing an electrophoretic medium, the method  
2 comprising:

3                   (a)     providing an electrophoretic medium having opposed first and  
4 second surfaces, the medium comprising a suspending fluid, a plurality of a first type of  
5 electrically charged particles having a first optical characteristic suspended in the  
6 suspending fluid, a plurality of a second type of electrically charged particles having a  
7 second optical characteristic different from the first optical characteristic, the first and  
8 second types of particles bearing charges of opposite polarity, the medium being  
9 characterized in that the first type of particles are magnetic, the second type of particles

are non-magnetic, and the medium further comprises a plurality of a third type of electrically charged non-magnetic particles having a third optical characteristic different from the first and second optical characteristics, the second and third types of particles bearing charges of the same polarity, but the second type of particles having higher electrophoretic mobility than the third type of particle;

the medium having a magnet disposed adjacent its first surface;

(b) applying to the medium an electric field having a polarity which causes the second and third types of particles to move adjacent the second surface of the medium with the second type of particles lying closer to the second surface, so that the second optical characteristic is visible at the second surface, the first type of particles lying adjacent the first surface of the medium;

(c) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second and third types of particles to move adjacent the first surface of the display, with the third type of particles lying closer to the second surface, the magnitude of the electric field being insufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces acting on the first type of particles, thereby causing the third optical characteristic to be visible at the second surface; and

(d) applying to the medium an electric field having a polarity and magnitude sufficient to cause the second and third types of particles to move adjacent the first surface of the medium, the magnitude of the electric field being sufficient to cause the first type of particles to move away from the first surface of the medium against the magnetic forces acting on the first type of particles and lie adjacent the second surface of the medium, thereby causing the first optical characteristic to be visible at the second surface.

22. A method of driving an electrophoretic medium to provide a threshold and/or to increase the number of optical states which can be displayed by the medium, the method comprising:

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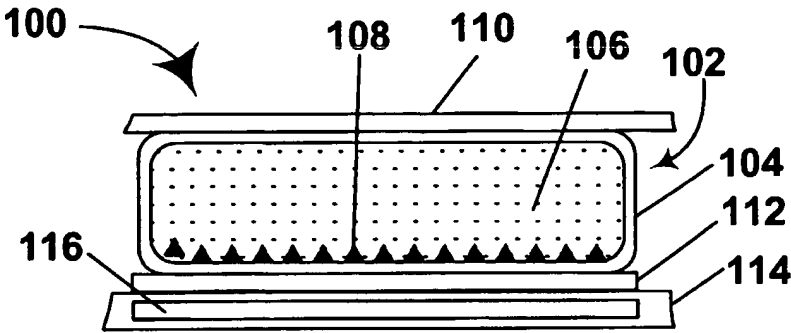


Fig. 1A

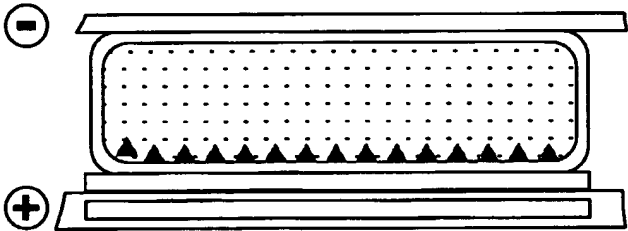


Fig. 1B

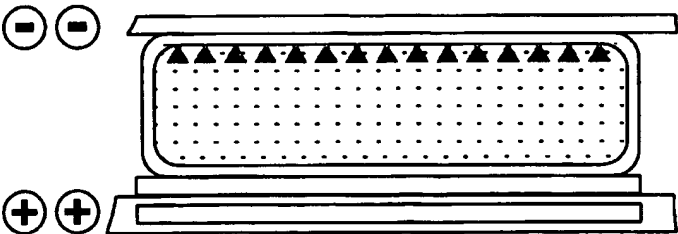


Fig. 1C

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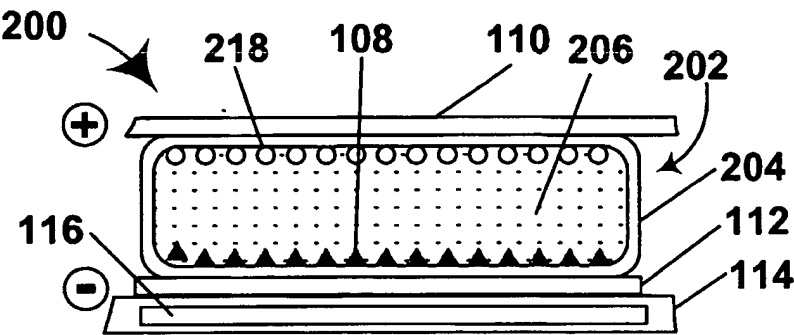


Fig. 2A

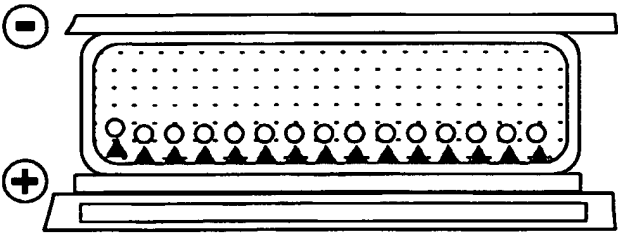


Fig. 2B

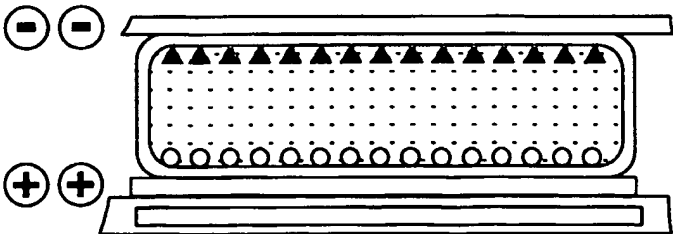


Fig. 2C

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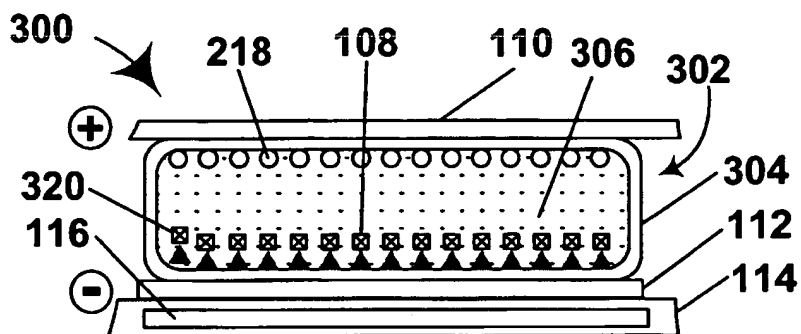


Fig. 3A

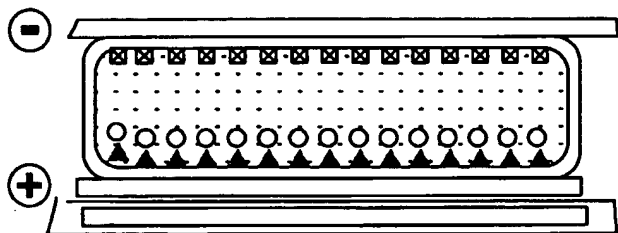


Fig. 3B

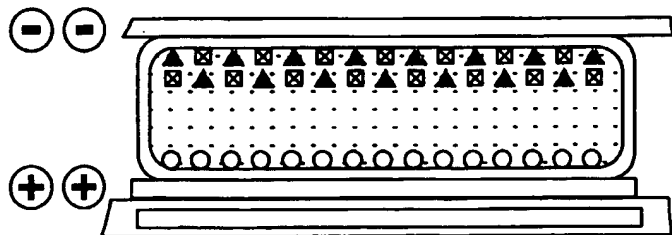


Fig. 3C

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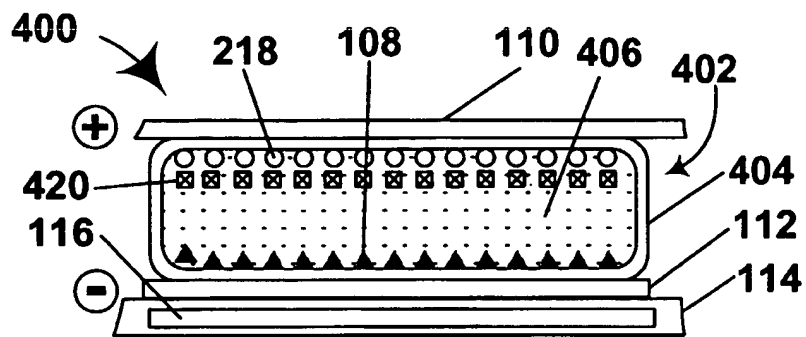


Fig. 4A

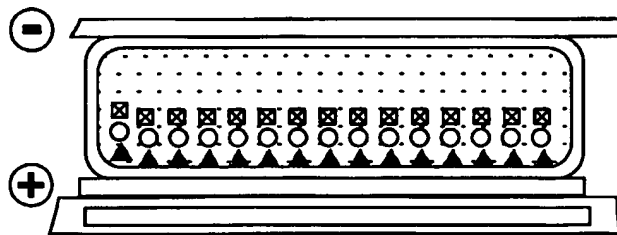


Fig. 4B

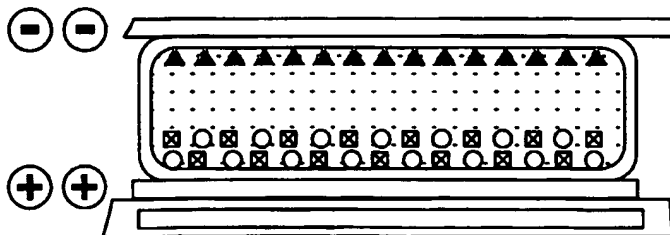


Fig. 4C

## INTERNATIONAL SEARCH REPORT

PCT/US 02/14542

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 G02F1/167

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, INSPEC, IBM-TDB, COMPENDEX

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 962 808 A (CANON KK) 8 December 1999 (1999-12-08)  paragraphs '0010!', '0012!'-'0015!', '0017!'-'0037!', '0047!', '0052!; claims; figures 1-8; examples 1-5 ---	1-3, 9, 11, 12, 15-18, 22
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

30 August 2002

Date of mailing of the international search report

06/09/2002

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PCT/US 02/14542

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